AD-A255 944

DOT/FAA/AM-92/26

Office of Aviation Medicine
Washington, D.C. 20591

Identifying Ability Requirements for Operators of Future Automated Air Traffic Control Systems

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August 1992

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-92/26		

4. Title and Subtitle Identifying Ability Requirements for Operators of Future Automated Air Traffic Control Systems	5. Report Date August 1992 6. Performing Organization Code
7. Author(s) Carol A. Manning, Ph.D. and Dana Broach, Ph.D.	8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, OK 73125	10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, D.C. 20591	13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

This work was performed under task AM-C-92-HRR-136.

16. Abstract

This study was conducted to anticipate the impact on air traffic controller ability requirements that may result from implementation of a future stage of air traffc control automation. If important changes occur in ability requirements, it will be necessary to develop or modify selection procedures for future air traffic controllers. Accurate identification of ability requirements depends on knowledge of the job tasks to be performed, but only general information is currently available about the job tasks associated with later stages of air traffic control automation. In this study, nine air traffic controllers who had analyzed operational requirements for a future stage of automation (a) described how controllers would perform four job tasks using the automation, (b) assessed the degree to which nine specific abilities were likely to be required to perform the automated tasks, and (c) assessed whether the amount of each ability required to perform the automated tasks would be different than the amount of the ability required to perform the equivalent tasks in the current system. The controllers thought that some changes will occur in the presentation of information, much of the requirement for verbal coordination will be removed, and much of the detailed information that the controller must be present will be supplanted by automation aids. At the same time, these controllers suggested that the future controller will have to have about the same levels as required today of the abilities discussed in the study to perform the tasks included in the study. They also did not think that any new abilities would be required to perform the job using extensive automation aids. As more information becomes available about the functioning of the automation and the controllers' interaction with it, it will be easier to define the associated ability requirements.

17. Key Words	18. Distribution Statement
Selection, Air Traffic Control, Ability Requirements Automation, Air Traffic Control	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	28	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

IDENTIFYING ABILITY REQUIREMENTS FOR OPERATORS OF FUTURE AUTOMATED AIR TRAFFIC CONTROL SYSTEMS

Introduction

Computers are increasingly being designed to perform duties previously performed by a human (Simon, 1987, Majchrzak, 1988). While awaiting the changes likely to occur in employees' jobs as a result of such automation, human resource managers should begin now to anticipate the impact these changes may have on requirements for selecting employees to operate the more automated systems. How functions are allocated between the operator and the automation will affect the complexity of the resulting job (Price & Pulliam, 1988). In some jobs automation might be configured to make most job-related decisions, leaving the employees to function primarily as monitors of system performance. In this circumstance, selection requirements for operators might be lowered because the complexity of job tasks would be reduced. In other jobs, automation might perform the repetitive tasks of a job, and allow the employee to perform more of the creative and evaluative activities. In this circumstance, operator selection requirements might be raised because the complexity of the job would be increased. While the amount of automation of any particular job will depend on the automation's efficiency in performing the associated job functions, some degree of automation is likely to be introduced in most jobs.

Anticipating how increased automation will affect the procedures used to select new employees is difficult when the role of automation in a job has not yet been defined. The extent of any job changes will depend in part on decisions made about the allocation of functions between the computer and the human operator. Furthermore, for complex automated systems, system development may be spread over a period of years, and job elements affected by automation may not be fully identified until close to implementation, when operational testing is underway. Moreover, last-minute testing may result in changes to the man-machine interface and operational procedures, influencing the degree to which certain abilities are required to perform a job.

Although it may be difficult to anticipate how automation will affect a job, it is advantageous to anticipate job changes well in advance so that appropriate selection criteria can be identified and implemented in at the same time as operational versions of automated systems. The Federal Aviation Administration (FAA) plans to introduce increasingly sophisticated levels of automation into air traffic control facilities over the next 20 years (U. S. Department of Transportation, 1984, 1989). The purpose of this study was to explore a method for identifying selection requirements for the Air Traffic Control Specialist (ATCS) occupation in anticipation of increased system automation.

Current Environment and Proposed Automation

The automation currently available in the air traffic control (ATC) system notifies a controller of aircraft locations and provides other relevant information. The ATCS makes decisions by incorporating information provided by the current automation with other information obtained from verbal pilot reports, Traffic Management, supervisors, and other controllers, then issues appropriate instructions and/or advisories to pilots. Thus, for the current ATC system, automation provides some of the required information to the ATCS, but the controller makes all the decisions and performs most of the operations required to *implement and communicate* those decisions.

The scope and sophistication of available ATC system automation varies across different types of facilities. Controllers work in 1 of 3 options or specialties: en route, terminal, and flight service station (FSS). FSS specialists provide services to pilots, such as giving weather briefings, filing flight plans, and giving navigational assistance to disoriented pilots. Some automation has already been introduced into FSS facilities, providing specialists with improved weather graphics and data and flight planning services. In fact, most of the automation-related job changes likely to affect the duties of the FSS specialist have already been introduced (U. S. Department of Transportation, 1978, 1980). Hundreds of small FSS facilities are being consolidated into a smaller number of automated facilities as part of an effort that has been underway since 1986. Further enhancements to the weather radar system and other automated systems will improve the quality of the information available to the FSS specialist, but probably will not result in significant changes in the way that specialists manipulate the available information. Because we perceive that FSS job tasks are not likely to change soon, this paper will not address the selection requirements for FSS specialists.

En route and terminal ATCSs ensure the separation of aircraft by using information about the speed, direction, and altitude of aircraft to formulate clearances and communicate them to pilots. Clearances are sets of instructions for pilots, designed to ensure the safe, expeditious, and orderly flow of traffic. En route controllers ensure the separation of those aircraft traveling between airports, while terminal controllers ensure the separation of aircraft approaching or departing from airports. There are 2 types of terminal controllers: terminal radar approach and departure controllers, who use radar to separate aircraft converging on or departing from an airport; and tower cab controllers, who control traffic landing at or taking off from an airport.

Initial stages of ATC automation in the form of the Initial Sector Suite System (ISSS; U. S. Department of Transportation, 1987) to be introduced prior to the year 2000 will provide en route controllers with new consoles on which they will have access to electronically displayed flight progress data and other information. However, the way controllers use that information to formulate and issue clearances will not change. Intermediate stages of automation in the form of the Area Control Computer Complex (ACCC) will introduce decision aids that will identify potential problems in a strategic time frame, (i.e., 15-20 minutes before occurrence) or through the end of the route of flight. These problems include conflicts between 2 or more aircraft, aircraft intrusions into restricted airspace, and aircraft noncompliance with flow instructions. Future software enhancements, such as Automated En Route ATC (AERA 2), will recommend solutions that optimize certain criteria, such as pilot preferences. Other automation (Data Link) may be introduced during this time to assist the controller by transmitting clearances digitally to a pilot, thus relieving the controller of some of the verbal communications requirements.

The Terminal Advanced Automation System (TAAS) will replace many of the current terminal air traffic control systems by the late 1990s. Terminal Air Traffic Control Automation (TATCA), a form of terminal automation that generates recommended actions for terminal radar approach controllers, will also be integrated into the TAAS. Both TAAS and TATCA should be introduced by the year 2000. Tower cab controllers will also have automation aids, provided as part of the Tower Control Computer Complex (TCCC). TCCCs will be installed from the mid-1990s to approximately 2005.

Facility consolidation will occur with the introduction of these stages of automation. Some terminal radar approach control facilities will be consolidated with en route centers into Area Control Facilities (ACFs). Other terminal facilities, based on geographical proximity, will be grouped and combined into metroplex control facilities. The remaining terminal facilities will continue to serve individual airports as local control facilities. Eventually, as en route and terminal radar functions are consolidated, the duties of en route and terminal radar approach controllers are likely to become similar through the use of the same type of equipment and some of the same procedures; however, terminal radar controllers will use tactical procedures more often than will the en route controllers. The job of the tower cab controller is likely to remain distinct from that of the radar controller.

Forecasting the Impact of Proposed Automation Changes on Job Functions

The introduction of the stages of automation described above will eventually reduce the amount of manual conflict detection performed by controllers, the time and effort needed for formulating and issuing air traffic control clearances, and the amount of verbal communications and coordination required with aircraft and other controllers. The planned automation will have a significant impact on the way air traffic controllers perform their jobs and also may affect the abilities required of future ATCSs.

Selection procedures for future ATCSs must be developed or modified if, in fact, important changes do occur in ability requirements for increasingly automated jobs. In order to design a selection system appropriate to the changing occupation, it is first necessary to identify the tasks that ATCSs will perform under increasing levels of automation, then enumerate the abilities that will be required to perform those tasks. Tests can then be identified or designed to assess the degree to which job applicants possess the abilities identified as necessary to perform the evolving job.

A number of issues must be considered before attempting to identify the abilities required to perform

jobs that do not yet exist. One issue relates to the availability of job task information. It is generally accepted that analyses of job functions should take place as early as possible (during the concept stage) in the system development cycle to ensure proper consideration in system design (Christensen, 1988). Updates to job task descriptions should occur as the system evolves. However, because the automated ATC system is currently evolving and decisions about the role of the controller with respect to the automation have not been finalized, the tasks likely to be performed by the future ATCS can presently only be described in a general way. Some of these decisions may not be finalized for several years; system design is not yet complete, and controller teams and human factors studies will provide feedback to the designers. This will result in system design changes, which may occur up until just before system implementation. One question that must be answered in this endeavor is "At what point in the system development cycle for a particular stage of automation should an analysis occur of the abilities required to perform the future controller's job?"

Another related issue deals with the evolution of automation enhancements. Introduction of early automation may not change the abilities required to perform the controller's job, while the introduction of intermediate and later stages of automation may result in significant changes in required abilities. The relevant question here is "At what stage of automation should the organization plan to introduce new or revised selection procedures?"

Strategic Job Analysis

Schneider and Konz (1989) discussed a technique called strategic job analysis to assess job tasks to be performed as well as the knowledges, skills, and abilities (KSAs) likely to be required to perform jobs that may change as a result of increasing automation. The process is, in some ways, similar to job analyses conducted for existing jobs. Traditional job analyses use a variety of methods to elicit information about tasks performed and the frequency and criticality of performance on those tasks from individual experts who perform the job, called Subject Matter Experts (SMEs; cf., Cornelius, 1988). Other information, such as the abilities required to perform the tasks (used to develop selection procedures), knowledges and skills required (when developing training programs or identifying recruitment strategies), working conditions and hazards (when identifying pay classifications), may also be obtained. This type of information is typically based upon SME judgments because they are most familiar with the job tasks performed and the requirements for performing those tasks. According to Schneider and Konz's (1989) approach, after the job tasks and KSAs have been identified for the current job, interviews are conducted with SMEs to identify factors that may affect a job as it is expected to exist in the future. The tasks and KSAs identified for the current version of the job are then revised in light of the expected changes. Revisions to the descriptions for the future job should be made periodically to take into account any changes in plans that might have occurred.

This process may be more difficult to implement than it would appear. Task descriptions, which can be very detailed for current jobs, may only be phrased in a general way for jobs that do not exist, or even if they are detailed, may change considerably as the specifications for the equipment and automation evolve. SMEs who contribute to the task descriptions can be very certain about how they perform the job currently, but no one, not even those SMEs who have been closely linked with the development of automation has ever performed the job using the future automation. Thus, current SMEs do not have the same level of expertise when describing future tasks.

In spite of the potential problems with this approach, some attempts have been made to identify the ATC tasks likely to change as a result of the introduction of different stages of system automation. CTA Inc., derived task, subtask, and task element descriptions, as well as task information requirements, cognitive/sensory attributes, and performance requirements for current and future ATC systems through extensive interactions with controller teams (Alexander, Alley, Ammerman, et al., 1988; Ammerman, Becker, Claussen, Inman, et al., 1987a; Ammerman, Becker, Claussen, et al., 1987b).

Ammerman and Jones (1988) then compared the tasks of the current en route controller with those to be performed by ATCSs operating ISSS equipment. They determined that when transitioning to ISSS, there will be little change in the results or output generated by ATCSs, but there will be some changes in how they perform the duties that support the generation of that output. Tasks to be affected most included those associated with reviewing and entering flight progress data. Also affected

will be actions dealing with adjusting displays, transferring control responsibilities, and processing of control data and messages. Phillips (1988) expanded this discussion to address tasks and skills associated with the processing of flight progress data that will occur when the information on flight progress strips is automated during ISSS implementation. He proposed that the greater flexibility associated with manipulating flight progress data using ISSS will result in an increased emphasis on skills in coding and sorting information, and a lower emphasis on physical manipulation of flight progress strips as a memory aid. While Phillips (1988) concluded that some changes in skills would occur after converting from the current en route air traffic equipment to ISSS equipment, he suggested that major changes would probably not occur in the underlying abilities required to control traffic. Thus, Phillips (1988) thought that new procedures probably need not be developed to select ATCSs who will operate ISSS equipment. Due to changes in the ISSS controller interface since Phillips' (1988) study, it may be necessary to reevaluate the required job tasks to confirm or disconfirm Phillips' (1988) predictions.

Assessing the job task changes, required abilities, and potential need for different selection procedures is less easily addressed for the AERA 2 level of automation. While considerable documentation is available about the proposed functions of the AERA levels of automation (e.g., Chambliss, Walker, Celio, and Sprague, 1990; Fordham, 1990; Kulik and Burke, 1990), not as much information is available to describe in detail the functions of the human in relation to the automation. Carlson & Rhodes (1990) compared the activities involved in detecting and resolving an aircraft conflict and responding to a pilot request in today's system with the corresponding activities for AERA 2. They did not, however, address other job tasks to be performed by the AERA controller. Celio (1990) provided some general operating guidelines for the AERA 2 controller. Celio, McCabe, and Schultheis (1990) provided activity sequences and operating guidelines for AERA controllers responding to an extensive set of specific scenarios. The activity sequences described the operation of the system and the controller's response to information displayed by the system.

Some have speculated that ability requirements may not change much with implementation of AERA 2 (McKinley and Jago, 1984). Other assessments of proposed automation aids suggest that the skills required to maintain the "mental picture" of the air traffic situation may be used less frequently when the automation is assigned the role of identifying most of the potential conflicts between aircraft (Whitfield, Ball, and Ord, 1980). Hopkin (1989) proposes that the use of automated problem detection could lead controllers to accept automation-generated problem resolutions routinely. He feels that controllers will either know less about how the system is functioning or will have to work harder than at present to maintain their mental picture. If these projections were true, future controllers might need a different set or mix of abilities and skills to maintain current levels of situational awareness, and thus, selection requirements might be changed.

Study Focus

This study was conducted to a) clarify the description of the role of the AERA 2 controller with respect to several AERA 2 controller job tasks, b) identify the abilities considered likely to be required for a controller to perform tasks using the AERA 2 system, and c) determine the differences between the abilities identified in b) with those required for the current system. While the AERA 2 level of automation is not yet finalized, the results of this study, given the current thinking about AERA 2 system functions, should allow some predictions to be made about whether modifications to current selection procedures should be considered.

METHOD

Subjects

Subjects were members of the Air Traffic AERA Concepts Team (ATACT). At the time of the study, ATACT had 11 members, 9 of whom participated in the study. The other 2 members did not attend the team meetings during which the study was conducted.

ATACT is a team of ATC specialists (including a military representative) that has met several times a year since 1985 to develop and analyze AERA 2 operational requirements. Through discussions and laboratory investigations, they develop and review AERA specifications and plans from the perspective of air traffic controllers. Members are selected for their operational expertise as well as their diverse backgrounds. ATACT members, ranging in age from approximately 30 to 50,

have a collective experience totaling more than 140 years of ATC worked in FAA centers, CERAPs, TRACONs, and towers throughout the United States, plus some military and foreign facilities. Additionally, they represent more than 35 years of staff (training, traffic management, data systems, procedures) and 25 years of supervisory experience. Most members have flying experience (private, instrument, instructor, commercial, combat, and air transport) and some have computer programming and data systems backgrounds. ATACT members have effectively drawn from their individual experiences, meshed their opinions, and spoken effectively to ensure the development of an operationally usable AERA 2.

PROCEDURE

The following section will discuss the procedures used to develop the materials presented to ATACT. First, the researchers identified important tasks using frequency and criticality estimates derived by Ammerman, Bergen, Davies, Hostetler, Inman, and Jones (1987). Next, the researchers developed flow charts containing the tasks to aid ATACT in their review. ATACT, as a group, recommended modifications to the flow charts, which were incorporated by the researchers. The researchers then developed a candidate set of 9 abilities and a group of questions to guide discussion regarding how those abilities might be required to perform the tasks identified above. ATACT members individually evaluated the tasks on each of the 9 abilities, then discussed their evaluations as a group. The process for conducting the study is discussed in more detail below.

Derivation of AERA 2 Controller Tasks

This section describes how a set of tasks was derived for use by the controller team in making judgments about ability requirements for AERA 2 controllers.

Identification of tasks. To identify the tasks to be used in the study, the researchers first obtained both tasks and associated frequency and criticality estimates from the CTA, Inc. Air Route Traffic Control Center (ARTCC) task analysis (Ammerman, et al., 1987). These tasks will hereafter be referred to as "en route HOST tasks" because they describe the en route controller's duties when operating the current en route HOST computer. A set of 24 en route HOST tasks was identified that had high ratings on both the frequency of occurrence and criticality dimensions, according to Ammerman, et al. (1987). The researchers then derived a set of 21 AERA 2 tasks from the descriptions provided by Celio, McCabe, & Schultheis (1990) and Fordham (1990).

Appendix A shows the en route HOST tasks and the AERA 2 tasks considered by the researchers to be functionally related. The en route HOST tasks for which no corresponding AERA 2 tasks were available were eliminated from consideration as part of this study (e.g., "Housekeeping, "Issuing and responding to pointouts"). ATACT had considered some issues related to Data Link, a future automation capability that will electronically transfer information between ATC automation and aircraft automation. However, a different controller team is responsible for defining Data Link requirements. Thus, this study did not address tasks involving Data Link, and those AERA 2 tasks addressing Data Link (e.g., "Communicate clearance to pilot via Data Link") were also eliminated from further consideration. Many of the remaining AERA 2 tasks appeared to be very similar. For example, the AERA 2 tasks "Perform Aircraft Conflict Resolution," "Perform Minimum Safe Altitude Processing," and "Perform Airspace Conflict Processing" appeared to include many of the same subtasks, and thus were considered equivalent.

The set of tasks chosen for the study addressed a variety of activities performed by controllers. These tasks included a) responding to pilot requests for a clearance change, b) responding to lateral or altitude conformance deviations, c) performing strategic aircraft conflict resolutions, and d) performing tactical aircraft conflict resolutions.

Elements or steps for each of the tasks listed above were developed using the Controller Activity Sequences (Celio, McCabe, and Schultheis, 1990) and the AERA 2 Operational Description (Fordham, 1990), and were displayed as flowcharts. The flowcharts were developed to initiate and promote discussion among ATACT about the specific duties associated with each task as they expected it would be performed by the AERA 2 controller.

Controller team review. The four preliminary task flowcharts described above were presented to ATACT at the beginning of a 4-hour review and discussion period. Comments made by ATACT members were recorded.

In response to the team's comments, new flow charts representing the relationships between elements of the tasks were prepared by researchers. The second set of flowcharts was then presented to the team at a second meeting held 3 months later. During a 2-hour session, the team reviewed and critiqued each task. The resulting comments were incorporated into a third set of flowcharts, shown in Appendix B. "Issue clearance to pilot," was identified as a subtask or "macro," and was split out from the other tasks because it occurred a number of times as a part of other tasks.

Several steps involving the evaluation and decision-making functions of the controller were made clear during the course of the controller review of the preliminary flowcharts. For example, in Task 1 ("Respond to pilot request for clearance change"), the steps proposed by the researchers as part of the original flow chart suggested that all pilot requests would be fed directly to the automation for evaluation without "preprocessing" by the controller. ATACT members pointed out that in the AERA 2 time frame, the controller would continue to make judgments about the validity of a pilot's request (in some sense, a "sanity check") to screen out improper requests and would submit only reasonable requests to the automation. The controllers also suggested that they might approve some requests immediately, without consulting the automation. The resulting Task 1 flowchart shows that the controller can determine the validity of a request and approve or deny it without first consulting the automation.

ATACT also pointed out that AERA 2 controllers will also use judgment in evaluating problem resolutions generated by the automation. A controller may not accept a highest ranked resolution (HRR) generated by the automation if he or she has information not yet available to the automation (e.g., weather hazards). A controller might also determine that if a requested routing is not acceptable because it would result in a conflict, it would be better to forward the resolution to Auto Replan (AR; a function that notifies the controller when a route previously requested eventually becomes available) rather than trying to identify alternative clearances that might achieve the same objective. The philosophy here was to let the system do the work, especially if the controller is busy.

Another point brought out during the discussions was that the controller will need to ensure the flight plan data base is updated to reflect changes in the system because the accuracy of the computations performed by the Automated Problem Detection (APD) software will depend on the currency of aircraft trajectories. For example, a pilot may request a flight plan change to avoid hazardous weather. When granting the request, the controller must also ensure that the current flight plan of the aircraft as present in the data base reflects this change. In most cases, this updating will be facilitated by features of the automation.

The situation in which a tactical maneuver is required to resolve a conflict is the AERA 2 task most similar to today's operations. Generally, the controller is expected to monitor the display for potential conflicts and not just rely on the automation to identify them. If a conflict alert occurs, conflict resolution advisories (CRAs) will be generated to assist a controller in maneuvering aircraft clear of each other. Implementation of a CRA will ensure a certain period of conflict-free flying, but will not necessarily include a clearance that allows the aircraft to continue to its destination. Once the potential conflict has been avoided, the controller will need to issue a clearance to enable the aircraft to continue on its desired route of flight. The controller will use his or her own judgment and the assistance of AERA tools to identify a flight path that will take the aircraft back on the desired route while establishing appropriate separation. Again, the controller will be required to ensure that the AERA flight plan data base reflects changes made to the aircraft's flight plan.

Initial Determination of AERA 2 Controller Abilities

Ability categories. Nine ability categories were identified, based on a review of the CTA Inc. HOST/ARTCC task analysis (Ammerman et al., 1987). The categories identified were Spatial Reasoning, Verbal Reasoning, Number Reasoning, Manual Dexterity, Selective Attention, Coding, Short-term Memory, Time Sharing, and Long-term Memory. The categorization of Spatial, Verbal, and Number Reasoning represents a partitioning of the complex, higher-order factors of general intelligence (Ackerman, 1988; Marshalek, Lohman, and Snow, 1983). Manual Dexterity, in contrast, reflects the less complex, more speeded response output component of this hierarchical model of abilities. The Coding and Selective Attention abilities were drawn from the cognitive-sensory attributes developed by

Ammerman, Fairhurst, Hostetler, & Jones (1987) in their analyses of the ATCS occupation. These abilities represent the perceptual speed factor or component in Ackerman's conceptualization of general intelligence. Short- and Long-term Memory, on the other hand, have been described as structural components of human abilities by researchers such as Shingledecker (1984) and Wickens (1984); Ammerman et al. (1987) also incorporated Short- and Long-term Memory into their taxonomy of cognitive-sensory attributes. Time Sharing is a specific construct of interest in ATCS selection research (Federal Aviation Administration, 1990; Stoloff, 1988). (The ability descriptions and related examples are shown in Appendix C.)

ATACT provided additional examples specific to air traffic control that could be added to descriptions of the abilities. Team members also discussed abilities that had not been included on the list. During the discussion, the team identified decision-making, problem identification, abstract reasoning, integration of information, and certain personality characteristics (e.g., "calmness under fire") as factors or abilities also needed for performance as an air traffic controller. It was suggested that some of these abilities might be encompassed, in part, by some of the abilities already listed, and that personality characteristics were deliberately not considered as part of this study.

Discussion questions. The researchers identified several areas of discussion to assist in ascertaining how the 9 abilities might be associated with performing the 4 AERA 2 tasks. The following questions were considered: "How important is this ability to acceptable performance of the task?," "How important is speed in using this ability to perform the task?," "Is this ability required to perform the task on the first day of On-the-Job Training (OJT)?," "How important is training in using this ability to perform the task?," and "How will the requirement for this ability in AERA 2 change from the current system?."

These questions were discussed to obtain an indication of the importance of each ability and how it could feasibly be used or developed. In some cases, it might be necessary for a student (developmental) controller to have an ability before beginning OJT; in other cases, some level of an ability could be acceptable, if it were further developed during OJT. Another factor of interest was whether it was acceptable simply to have the ability, or if speed of its use was also an important determinant of success. Moreover, ability domains identified as important and needed on the first day of OJT would be logical candidates for inclusion in future selection batteries. Those not needed the first day of OJT might be considered skills, which could be further developed later during OJT.

The final question addressed the requirement for each ability in the AERA 2 time frame, as compared with the requirement for it in the current system. The researchers expected that understanding the controllers' assessments of the relationship between current and future requirements would be made clearer through oral discussions.

Process

The abilities and discussion questions were explained to ATACT using the handout shown in Appendix C. Team members were asked to evaluate each question independently for each task as a way of initiating discussion. First, team members independently evaluated all questions related to 1 task before proceeding to the next. The flow charts from Appendix B were provided for the controllers to use as reference materials. Members were asked to consider each task as a whole. If an ability was required to perform a part of the task, then it was to be considered required to perform the whole task. Second, the evaluations were discussed by the group to discover the reasoning behind their individual evaluations. Counts of individual evaluations were made and comments provided by the controllers during the group discussion were recorded.

Before beginning, the team independently evaluated and discussed questions about how the Spatial Reasoning and Verbal Reasoning abilities related to the sample macro task, "Issue Clearance to Pilot," to become familiar with how the process was intended to work.

RESULTS

Question 1: Importance. Two-thirds or more of the team indicated that each ability was important for each of the 4 tasks, with the exception of Number Reasoning. Only 4 of the 9 controllers thought that Number Reasoning would be important when processing conformance deviations and resolving conflicts in strategic situations. Team members who thought Number Reasoning would not be very important for those tasks

indicated that the automation would perform many of the numerical calculations. Moreover, much of the presentation of information in the AERA 2 time frame would be in a graphical form, requiring less explicit numerical computation by the controller.

It is also interesting to note that all controllers thought Coding would be very important in performing the AERA 2 tasks included in the study. Team members indicated that the type of data the AERA 2 controller would be required to process would be much different than the type of data processed today. The requirement to convert or decode certain information (e.g., flight progress data) will be reduced somewhat in AERA 2 because the automation tools will provide that service. However, the system will provide a considerable amount of other types of information (e.g., trial plans, shorthand representations for clearances) that the AERA 2 controller will have to interpret.

Every member of the team thought that Spatial Reasoning would be important in performing all tasks except "Process conformance deviations." All but 1 thought Spatial Reasoning would be important for that task. It was thought that Spatial Reasoning would be important in interpreting the graphic information provided by the automation and in becoming oriented to the problems identified by the automation.

Question 2: Speed. Two-thirds or more of the controllers thought that speed in using most of the abilities would be important in performing most of the tasks. Four of the 9 controllers thought that speed in using Number Reasoning would be of little importance in processing conformance deviations and resolving conflicts in strategic situations. This result would be expected, given that the same controllers did not think that Number Reasoning was very important for performing those tasks. Also, only 4 of the 9 participants thought that speed would be important when using Verbal Reasoning to resolve conflicts in strategic situations. Their reasoning was that in the AERA 2 time frame, there should be much less verbal communication required with a pilot overall, although when communication was required, it would be very important.

Only 5 of the 9 controllers thought that speed in using Selective Attention would be important in addressing pilot requests for clearance changes, and that speed in using Short-Term Memory would be important in processing conformance deviations. Those who thought that speed was not important in using Selective Attention to process pilot requests for clearance changes indicated that there would be fewer distractions in the AERA 2 time frame because, among other reasons, there should be fewer pilots on the radio due to increased use of Data Link. Those who thought that speed in using Short-Term Memory would not be important in processing conformance deviations indicated that speed will be required in solving problems, but the reconformance issue will not usually involve a problem. Most of the time the automation will already reconform the trajectory to match the path of flight, and most of the communication with the pilot would be to ensure that the pilot's intentions match the flight plan data base. In general, however, it was considered that most of the information to be remembered would be available through the automation and thus, speed in using Short-Term Memory would be of relatively little importance to job performance.

All of the team thought that speed in Coding would be important when performing all tasks except resolving conflicts in strategic situations. On that task, all but one thought that speed of Coding would be important because Coding occurs before most of the other abilities are used.

Question 3: Needed first day of OJT. Two-thirds or more of the controllers thought that most of the abilities would be required to perform most of the tasks on the first day of OJT. The most notable exceptions were that the team split (4 vs. 5 or 5 vs. 4) on whether they thought Selective Attention would be necessary on the first day of OJT when dealing with pilot requests for clearance change, processing conformance deviations, and resolving conflicts in a strategic mode. Those who thought that Selective Attention was not important on the first day of OJT considered it to be more of a skill than an ability — in the sense that it could be developed, or improved upon over time. They also indicated that in some tasks, notably processing conformance deviations, there will be more time to analyze the situation and fewer activities competing for attention. Therefore, the developmental controller could probably be taught how to perform the task as an isolated activity, not requiring as much Selective Attention as other tasks.

Only 4 of the 9 team members thought that Time Sharing would be required on the first day of OJT when resolving conflicts in a strategic mode. Those who dis-

agreed thought that if the developmental had the concepts of time sharing, given that the steps involved in conflict resolution would be performed in a different sequence than presently, then utilizing Time Sharing could be developed over time and would not be necessary when beginning OJT.

Only 3 of the 9 team members thought that Number Reasoning would be required for the first day of OJT when processing conformance deviations. Those who thought Number Reasoning would be important on the first day of OJT thought that both Spatial and Number Reasoning would be used to observe aircraft drift. Those that thought it would not be important on the first day of OJT thought that it was less important than the other abilities in the performance of this task because most of the time the automation would have already reconformed the aircraft's flight trajectory; the controller would have to perform this task only under unusual circumstances.

All of the team members thought that Spatial Reasoning would be required on the first day of OJT when performing all tasks, except processing conformance deviations. For that task, all but one thought Spatial Reasoning would be required on the first day of OJT. It was thought that Spatial Reasoning would be important in interpreting the graphic information provided by the automation and in evaluating alternative resolutions. A certain amount of Spatial Reasoning should be required when the developmental starts training, but most of the controllers also thought that the use of Spatial Reasoning could be enhanced through training.

All of the team thought that Short Term Memory would be required on the first day of OJT to perform all tasks, but Process Conformance Deviations; for that task, all but 2 thought that Short Term Memory would be required on the first day of OJT. It was thought that it was difficult to teach Short Term Memory skills so, for the most part, they would need to be present on the first day of OJT.

Question 4: Enhancement by training. Two thirds or more of the team indicated that training would enhance the use of abilities for every task. It is interesting to note that all team members thought that Spatial Reasoning and Coding could be enhanced through training for all the tasks. It is also interesting to note that all but 1 controller thought that all abilities could be enhanced through training when resolving conflicts in a tactical situation.

Question 5: Change in requirement for abilities. There was considerable variation in the assessments of changes in ability requirements; for a number of tasks, several controllers thought the requirement for an ability would be higher, while for the same tasks, other controllers thought the requirement would be lower. However, there were some trends in the data.

The team members thought that there would be almost no change in the abilities required to resolve conflicts in a tactical situation. Although the CRA automation will provide a proposed resolution to the controller, the team thought that the requirement to rapidly evaluate an automation-generated resolution should not be much different than today's requirement to quickly evaluate controller-generated resolutions.

The team thought that the requirement for Verbal Reasoning and Short Term Memory in the 4 tasks would be virtually the same in the AERA 2 time frame as it was at the time of the study. The team indicated that any time there was a requirement to talk with a pilot, Verbal Reasoning would be important. Just as Verbal Reasoning is important in today's ATC system, it will continue to be important in the future, although the frequency of it's use may be lower, due to increased reliance upon Data Link. Short Term Memory requirements may change with respect to the specific information to be remembered, but there will always be some information that the controller will have to remember for short periods of time.

Five of the 9 team members thought that the requirement for Number Reasoning would be reduced when processing pilot requests for clearance change in the AERA 2 time frame. The team members indicated that many of the calculations currently required to perform that task would be performed by the automation. While an AERA 2 controller will still need to use Number Reasoning to perform the task, the automation will provide considerable assistance.

Six of the 9 members of ATACT thought that there would be a higher requirement for Manual Dexterity when processing pilot requests for clearance change, and when resolving conflicts in a strategic situation. Some of

the team members indicated that AERA 2 automation was being designed to minimize "button pushing" and that there would be less to be typed. Others indicated that in today's system not much data entry is required. They thought that a certain amount of data entry will be required when constructing the problem for the automation to examine. It seemed that, while it might be necessary to "pound" fewer keys, Manual Dexterity would still be important in locating the appropriate function keys quickly. In general, the feeling was that "the faster you are with the keyboard, the better off you will be."

There was also some difference of opinion about the change in the need for Manual Dexterity when processing conformance deviations, and in using Selective Attention, when processing pilot requests for clearance change. Some team members thought that keyboard entry would occur less frequently when processing conformance deviations, unless a pilot's clearance needs to be changed. Other team members thought that when there is a requirement to change a clearance, it would have to be done quickly, thus increasing the requirement for Manual Dexterity.

Regarding the requirement for Selective Attention, some controllers thought that there would be fewer events occurring simultaneously in the AERA 2 time frame (most notably fewer pilots using radio frequencies) and thus the requirement for Selective Attention would be less. Others thought that there would be other things going on in the sector and that Selective Attention would still be required when processing clearance change requests.

Five of the 9 team members thought that implementation of AERA 2 would increase the requirement for Coding when processing pilot requests for clearance change, and 7 of the 9 thought that it would increase the requirement for Coding when resolving conflicts in a strategic situation. Team members indicated that Coding is not required extensively when evaluating separation in today's system, but will be in AERA 2.

Finally, there was some disagreement about the role of a number of abilities in processing pilot requests for clearance change and resolving conflicts in a strategic mode. Four team members thought the requirement for Spatial Reasoning would be more important for processing pilot requests for clearance change in the AERA 2 time frame than at present, while 2 thought it would be less than at present. Also, 3 team members thought the requirement for Spatial Reasoning would be more important for *resolving conflicts in a strategic role in the* AERA 2 time frame than at present, while 2 thought it would be less than at present. Those who thought Spatial Reasoning would be less important said that, since the flight progress data would be in a graphic mode, it would be easier to understand, and thus would require less Spatial Reasoning. Those who thought Spatial Reasoning would be more important said that, due to increasing traffic volume, the AERA 2 controller would likely be required to solve more problems than at present and would not always take the time to use the graphical displays. Also, they thought that increased Spatial Reasoning ability would be required for orientation to the problem presented by the automation.

Two controllers thought the requirement for Long-Term Memory would be more important for processing pilot requests for clearance change in the AERA 2 time frame than at present, while 2 thought it would be less than at present. Also, 4 controllers thought the requirement for Long-Term Memory would be more important *for resolving conflicts in a strategic role in the* AERA 2 time frame than at present, while 2 thought it would be less than at present. Those who thought that Long-Term Memory would be more important indicated that, based on current ACCC and AERA 2 specifications, there will be 130 controller commands and that Long-Term Memory will play a big role if all the steps are performed when evaluating a possible resolution. Those who thought Long-Term Memory would be less important said that there are a lot of things to remember, but that the automation will do most of the remembering for the controller. For example, controllers will no longer have to remember the appropriate radio frequencies for pilots to tune in when crossing sector boundaries.

CONCLUSIONS

Preliminary findings. In spite of a number of factors that might limit the interpretability of these results (discussed below), the oral discussions of ATACT indicated that a number of changes in controller tasks would occur in the AERA 2 time frame. The team thought that the AERA 2 controller's reliance on textual presentation of flight progress data should be reduced because data would be more often displayed in graphic form. The requirement to sort rapidly through the current graphic

and textual information to identify problems will be reduced significantly, with the automation identifying most problems. AERA 2 will greatly reduce the need for verbal coordination with other sectors. Many of the details that a controller must remember at present will be supplanted by automation aids, although it appears that other types of detail may be important in the AERA 2 time frame. For example, the AERA 2 controller will have to remember the command structure and capabilities of the automation.

On the other hand, the automation will enhance the controller's view of the system so that he or she can develop a broader perspective of system events than is currently feasible. In today's system, the controller can foresee some events well in advance, but has limited information available about events occurring outside his/her own sector. Without coordination with others, today's controllers have limited knowledge of events occurring outside their sector, although they can take actions that will affect other controllers. In the AERA 2 time frame, the aircraft that the controller will be able to examine and influence will expand across both sectors and time. As a result, the AERA 2 controller will increasingly issue clearances to prevent the development of problems predicted to occur in another controller's sector.

Some activities are likely to remain the same. There will still be a need to communicate with pilots. There will be times when a controller will have to take steps to separate aircraft, without the help of an automated problem detection or resolution tool. The AERA 2 controller will still need to analyze all situations to make decisions and solve problems, both short- and long-term.

There will be some tradeoffs in activity. Although the goals of those designing the system are to support an effective interface between controller and the system, team members indicated that to fully utilize the system, keyboard manipulation will still be required. While translation and interpretation of some data will be reduced, the types of data to be processed should be different in the AERA 2 time frame, so data translation and interpretation in some form (e.g., Coding) will still be important. More translation and data interpretation will be necessary if less keyboard activity occurs.

Some team members observed that the AERA 2 system was oriented toward today's controller and that it was probably designed to perpetuate the way air traffic controllers manage traffic in the current nonautomated environment. Others thought that there might be a tendency to sit back and let the system run without much involvement. They said that it would take work for an AERA 2 controller to become involved and maintain effective interaction with the system.

What do these discussions mean when trying to identify the abilities required to perform the job of AERA 2 controller? ATACT members' evaluations of questions regarding change in ability requirements and their oral evaluations indicated that AERA 2 controllers should have about the same high levels of most of the nine broad abilities discussed in order to perform the tasks examined in this study. ATACT was unable to determine analytically that the requirement for any of the abilities required to perform the job of air traffic controller in the en route/HOST environment would be notably different in the AERA 2 environment. Also, they found nothing to suggest that any additional abilities not currently required would be required in the AERA 2 time frame. Thus, it appears that selection procedures identified as being appropriate for today's controller may also be appropriate for the AERA 2 controller.

Limitations. A number of factors could limit the interpretability of this study. The study addressed only 4 of the tasks to be performed by the AERA 2 controller. Examination of other tasks could result in identification of different relationships between abilities and task performance. Expansion or modification of the abilities list may also be appropriate to identify all requisite abilities for the AERA 2 controller.

It is possible that the SMEs could have overestimated the similarity between the requirements for performing the job in the AERA 2 time frame, as compared with performing the job in its current form. Previous research suggests that people tend to believe that events they can recall or imagine generally occur more frequently than events they do not recall or cannot easily imagine (Tversky & Kahneman, 1974). Having difficulty in imagining circumstances requiring the use of different abilities to perform the job of AERA 2 controller could affect SMEs' expectations about their relevance in performing the job.

Such biases may have operated in other SME assessments of future jobs. Schneider and Konz (1989) found that "incumbents' views of tasks and KSAs for today's jobs are generally highly correlated with SMEs' projections of the future," though they cautioned that "high correlation does not equal agreement." It will be important to identify the aspects of the future job on which the SMEs focus when making their ratings, and what kinds of processes they use to make their ratings.

While there have been extensive analyses and discussions of AERA 2 requirements, it is very early in the development cycle. ATACT's opinions in this report are based on these discussions and limited prototype laboratory experience, rather than actual job performance. Further, more sophisticated, laboratory investigations could affect the results of this study.

After this study was conducted, the researchers met with the controller team to review an early draft of this document. The team had just observed a prototype demonstration of AERA 2 data displays. While the prototype reflected many of ATACT's operational requirements, most members thought that it displayed more data than were needed for operational use. It was pointed out that reactions to such demonstrations would produce a re-examination of requirements, which could result in changes to requirements. Therefore, the team felt that definitive statements about the duties of the AERA 2 controller or the abilities required of the AERA 2 controller were premature at the time of this study.

ATACT's familiarity with the system will increase as additional prototypes are developed and tested. Plans for how the AERA 2 controller will interact with the automation may also change before the system is implemented. These factors make it necessary to re-examine this topic and replicate and extend this study over time, before the system goes on line, using a larger controller sample that has some prototype and operational test and evaluation experience with AERA 2.

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Appendix A

Comparison of Controller Tasks in En Route HOST and AERA 2 Environments

Activity 1: Perform situation monitoring

1. En Route HOST tasks	2. Related AERA 2 tasks
Checking and evaluating separation	Observe computer-generated alert Conflict alert
Processing departure/en route time information	Generate resolution through single aircraft planning
Housekeeping	Not covered

Activity 2: Resolve aircraft conflictions

1. En route HOST tasks	2. Related AERA 2 tasks
Perform aircraft conflict resolution	Observe computer-generated alert Assess operational suitability of automation-generated resolutions Obtain additional problem information Review and evaluate operational feasibility of lower ranked resolutions Generate resolution through single aircraft planning Implement problem resolution Conflict alert
Perform minimum safe altitude processing	Observe computer-generated alert Assess operational suitability of automation-generated resolutions Obtain additional problem information Review and evaluate operational feasibility of lower ranked resolutions Generate resolution through single aircraft planning Implement problem resolution Conflict alert
Perform airspace conflict processing	Observe computer-generated alert Assess operational suitability of automation-generated resolutions Obtain additional problem information Review and evaluate operational feasibility of lower ranked resolutions Generate resolution through single aircraft planning Implement problem resolution Conflict alert
Issuing unsafe condition advisories	Resolve problem unknown to automation Provide VFR traffic advisories for aircraft without altitude encoding transponders

Activity 3: Manage air traffic sequences

1. En route HOST tasks	2. Related AERA 2 tasks
Respond to traffic management constraints/flow conflicts	Observe computer-generated alert Assess operational suitability of automation-generated resolutions Obtain additional problem information Review and evaluate operational feasibility of lower ranked resolutions Generate resolution through single aircraft planning Implement problem resolution
Processing deviations	Out of conformance - descent, lateral deviation Observe computer-generated alert Assess operational suitability of automation-generated resolutions
Establishing arrival sequences	Obtain additional problem information Review and evaluate operational feasibility of lower ranked resolutions Generate resolution through single aircraft planning Implement problem resolution Resolve problem unknown to automation
Managing departure flows	Observe computer-generated alert Assess operational suitability of automation-generated resolutions Obtain additional problem information Review and evaluate operational feasibility of lower ranked resolutions Generate resolution through single aircraft planning Implement problem resolution Resolve problem unknown to automation

Activity 4: Route or plan flights

1. En route HOST tasks	2. Related AERA 2 tasks
Planning clearances	Generate resolution through single aircraft planning
Responding to contingencies	Not covered
Reviewing flight plans	Pilot request for IFR clearance
Processing flight plan amendments	Pilot request for clearance change
Receiving transfer of control/radar information	Control transfer acceptance
Initiating transfer of control/radar information	Control transfer initiation
Issuing pointouts	Not covered
Responding to pointouts	Not covered
Issuing clearances	Communicate clearance to pilot via data link Communicate clearance to pilot via radio
Establishing, maintaining, and terminating radio communications	Transfer of communications - Initiating sector Transfer of communications - Receiving sector
Establishing/re-establishing radar identification	Transfer of communications - Receiving sector

Activity 5: Assess weather impact

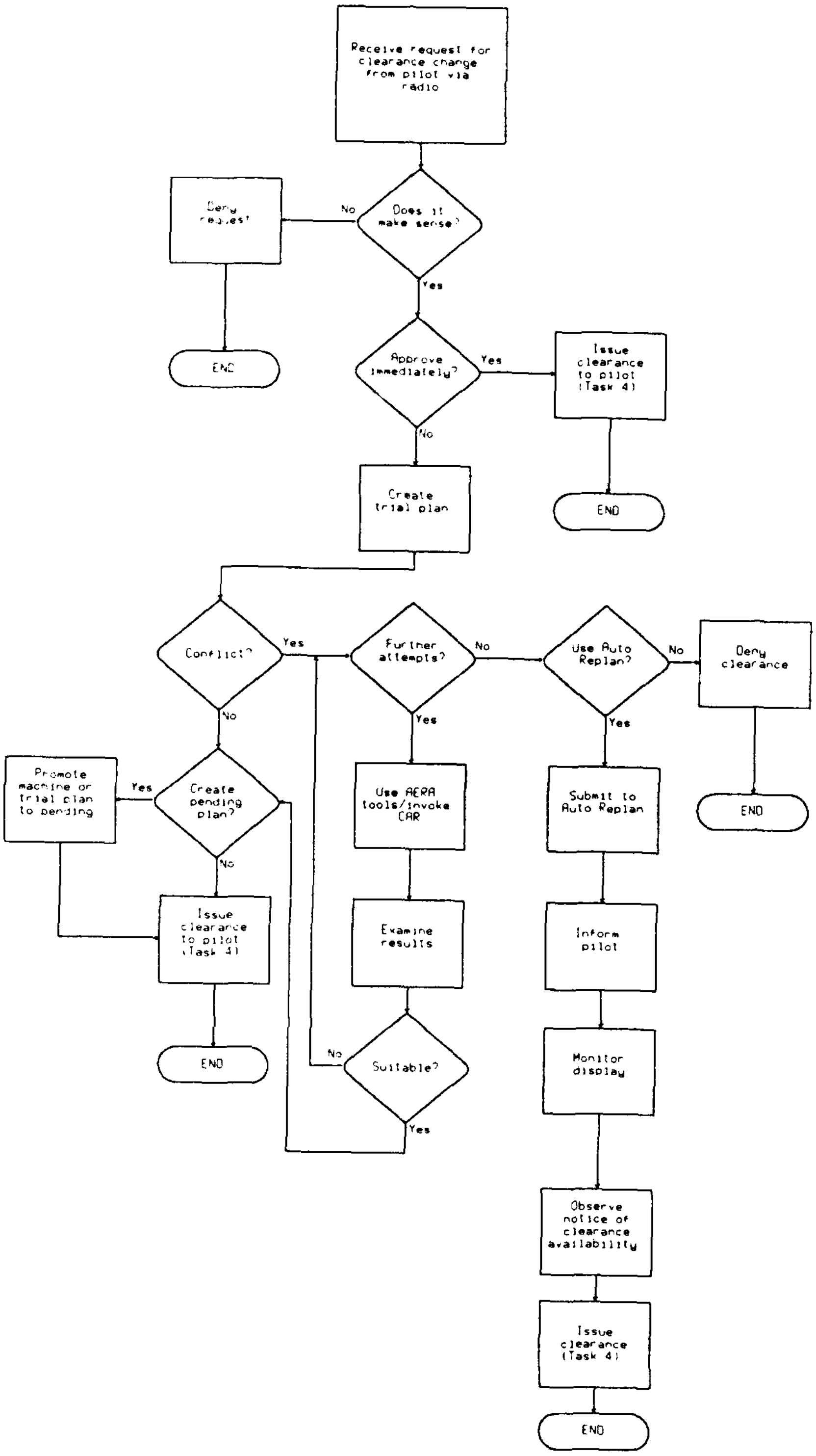
1. En route HOST tasks	2. Related AERA 2 tasks
Processing weather reports	Obtain additional probleminformation

Activity 6: Manage sector/position resources

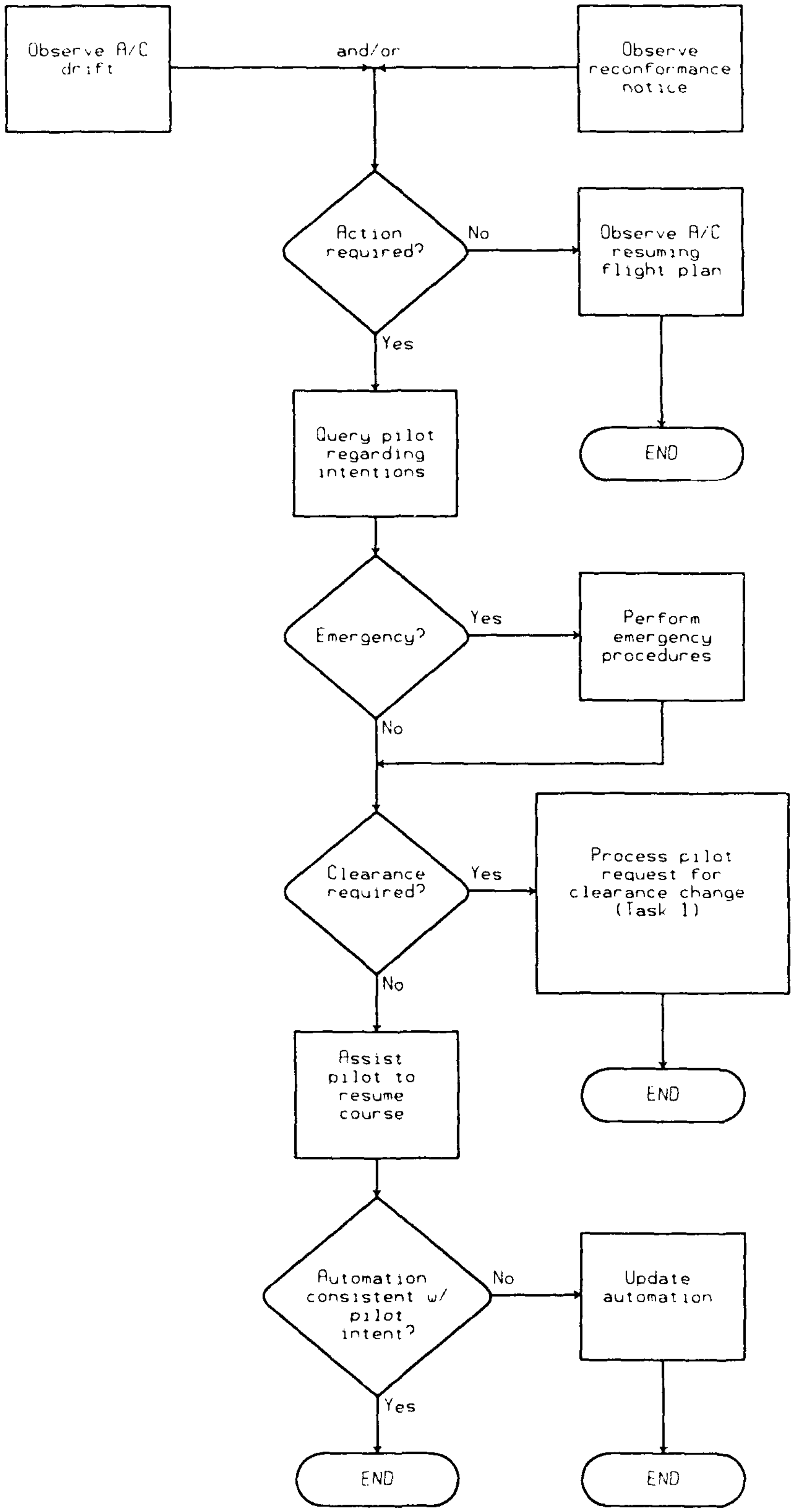
1. En route HOST tasks	2. Related AERA 2 tasks
Assuming position responsibility	Not covered

Appendix B
AERA 2 Task Flow Charts

AERA Task 1 Respond to pilot request for clearance change

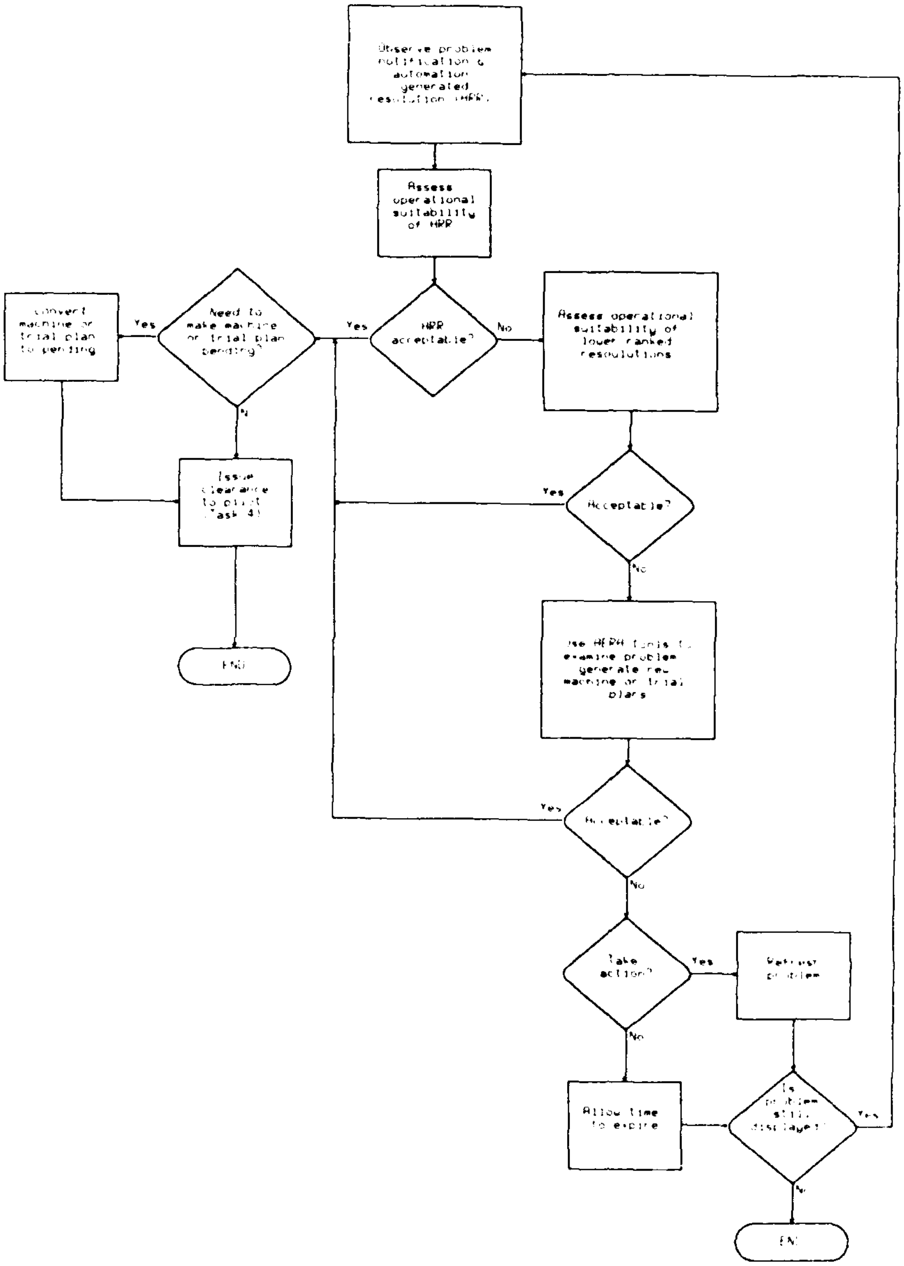


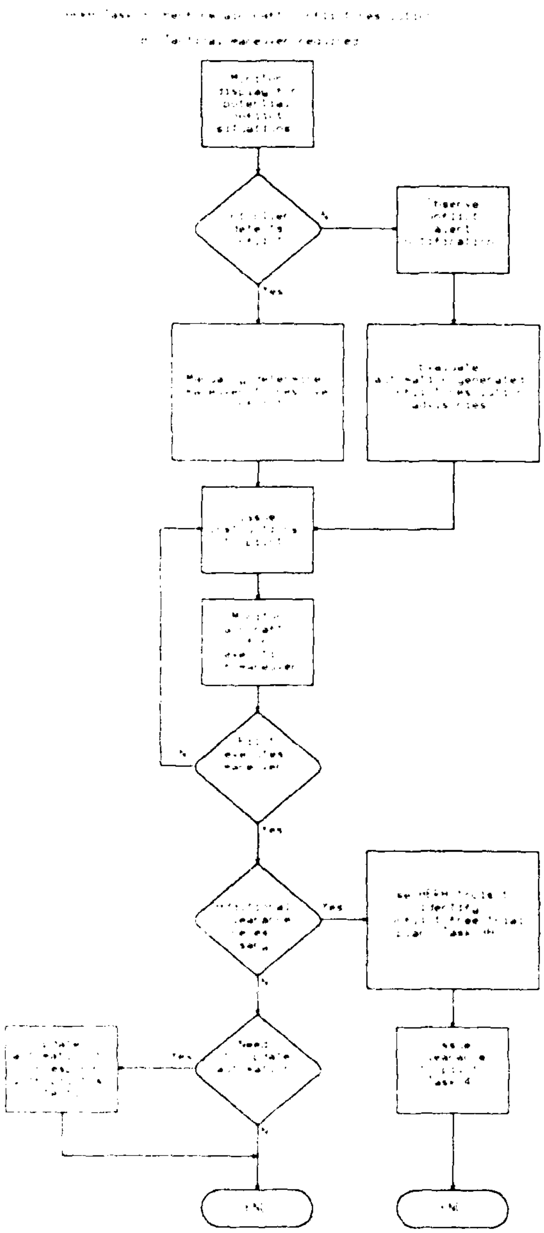
AERA Task 2: Process Conformance Deviations



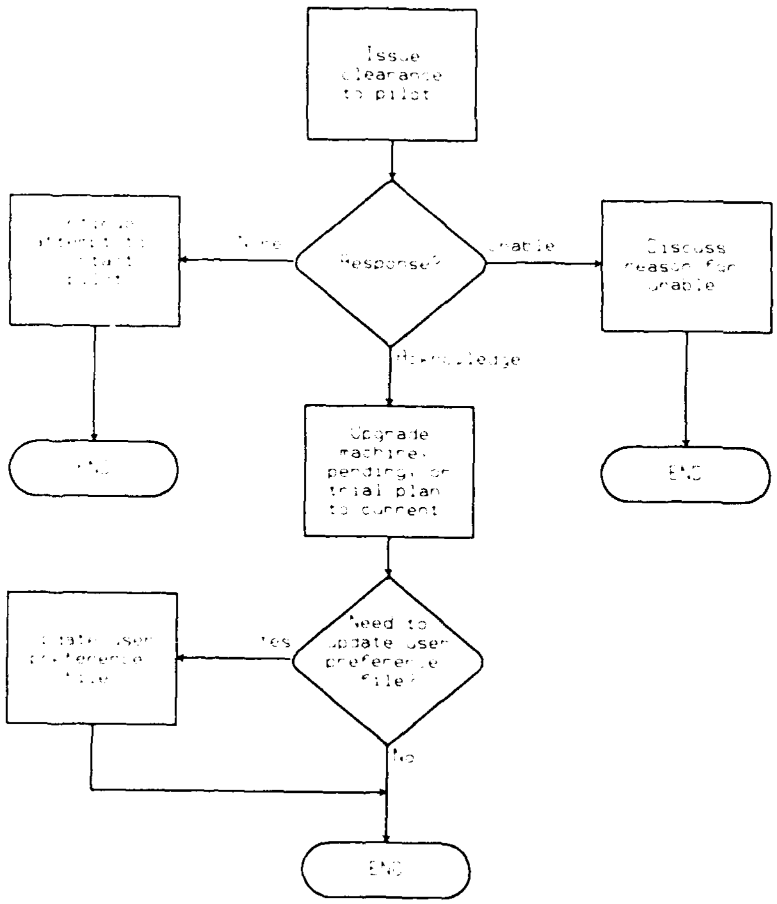
AERA Task 3: Perform aircraft conflict resolution

H. Strategic maneuver required





Task 4: Issue clearance to pilot



Appendix C

MEETING WITH ATACT MAY 20-21, 1991
AERA 2 ABILITY REQUIREMENTS

Purpose

The purpose of this meeting is to identify human abilities that are likely to be required to perform a set of AERA 2 controller tasks.

Process

First, the AERA 2 task descriptions will be reviewed. These task descriptions are based on input from ATACT in February, 1991.

Second, descriptions of selected human abilities will be reviewed with the team. The rating scales to be used to assess the requirement for those abilities will also be discussed.

Third, team members will evaluate which abilities might be required to perform each AERA 2 task at an acceptable level of performance.

Fourth, ATACT will be asked to develop a group consensus on the abilities that might be required to perform each AERA 2 task.

HUMAN ABILITIES

Ability

Ability, in personnel psychology, is what a person brings to the job situation without benefit of specialized, job-specific training, education, or experience. Ability, at that point, has already been shaped by general education and experience. However, people do not all have the same levels of abilities as they come into a job situation. Consider, for example, the ability to read. The ability to read is the product of education and practice prior to employment. Yet for a variety of reasons, ranging from native intelligence to the curriculum used to teach reading, the ability to read varies from person to person. Some people can read complex materials easily and quickly, while others struggle with a newspaper. The person that reads well will have less difficulty in a job task requiring reading than a person who's reading skills are not as strong, while their job performance may be exactly the same on another task in which reading is not even required.

There are many kinds of abilities. Our focus is on relatively broad mental abilities. Mental abilities are the fundamental, basic, and to some degree abstract, capacities and processes of thinking, perceiving, and deciding. Mental abilities are the operations of the mind, not to be confused with the content (for example, aircraft performance characteristics) or the product (a clearance), or the quality of the performance.

Knowledge and skill

Knowledge and skill, in contrast, are the products of job-specific, specialized training, education, and experience. Knowledge is the job-specific content or information used by the mental abilities. Skill is the quality of performance based on the combination of ability and knowledge after practice and training on a task. Skills are specific to job tasks; knowledges are specific to jobs; but abilities are relatively independent of specific jobs. Knowledge and skill improve, often dramatically, with instruction and practice. Knowledge and skill are acquired rather than innate. For example, a developmental controller is instructed in aircraft performance characteristics. A controller learns to separate aircraft through instruction and practice. In a sense, knowledge and skill are built upon the foundation of mental abilities that a person brings to the situation.

Definitions of human abilities

We have identified a number of abilities which describe some of the human capacities likely to be involved in air traffic control. We have excluded from this list some abilities that we assume all controllers must have, such as the ability to see or hear.

Human Mental Abilities and ATC Examples

Ability	ATC Example
Spatial reasoning The ability to recognize, combine, separate, and manipulate figures, graphics, or other spatial data in order to solve a problem	Scanning PVD and using aircraft tracks to identify potential conflict situations
Verbal reasoning The ability to recognize, combine, separate, and manipulate words according to the rules of logic and grammar	Understanding pilot request for altitude change due to air turbulence at the assigned altitude
Number reasoning The ability to recognize, combine, separate, and manipulate numbers according to the rules of arithmetic and mathematics	Computing the estimated time of arrival for a general aviation aircraft from filed airspeed and distance to be traveled on route
Manual dexterity The ability to use one's limbs (hands, feet, etc.) in a smooth, coordinated, error-free manner to manipulate objects	Slewing the cursor onto a target using the trackball
Selective attention The ability to concentrate attention on a single stimulus in the presence of distractors	Listening to a single aircraft's transmission against background noise
Coding The ability to convert information from one form or mode to another	Translating a heading reported by a pilot into the aircraft's track on a graphic display
Short-term memory The ability to keep a piece of information in mind and recall it exactly for a short time	Saying a clearance, keeping it in mind while the pilot reads it back and comparing the readback to what was said
Timesharing The ability to perform multiple activities at the same time	Saying a clearance while writing the clearance on the strip at the same time
Long-term memory The ability to learn and recall information for a long time	Recalling aircraft performance characteristics learned in follow-on training three years ago

*U.S. GOVERNMENT PRINTING OFFICE: 1992-661-063/60025